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ON THE ANALYSIS OF CLEAR AIR RADAR ECHOES SEVERELY CONTAMINATED BY CLUTTER

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Introduction

Many radar systems work in environments where clutter returns overwhelm the atmospheric echoes. Sometimes by as much as 50 dB.

At the Arecibo Observatory (AO), for example, clutter levels are conspicuously high. This situation greatly reduces its usefulness for lower atmospheric studies. It is not possible in general, to observe height profiles of the vertical component of the wind velocity. This parameter is important to understand planetary scale circulation, mountain and lee waves, turbulence, tropospheric and stratospheric interactions and vertical transport of horizontal momentum. Moreover, and to show another aspect of the problem, it has been suggested (Gonzalez and Ierkic, 1993) that clutter returns may sometimes be confused for atmospheric echoes.

There is growing interest to find practical ways to counteract the deleterious effects of clutter, noise, interference, and of non-ideal radar equipment. Techniques that have been proposed include Adaptive Radar Signal Processors (Farina and Studer, 1987) and Least Squares Fitting Methods (Yamamoto et al., 1988). Of course, these techniques are non exclusive.

Few workers have recognized the importance of understanding the origin and propagation characteristics of the various contaminating signals,in particular of the clutter. This understanding can be used to formulate the Rules of a Knowledge- Based System that directs the Data Analysis Process (Gowrishankar and Bourbakis, 1992; Sigillito and Hutton, 1990). It is convenient that the resulting Expert System operates in the frequency domain and that the data analysis consists of the parameterization of spectra using non-linear fitting methods (Numerical Recipes, 1992). The analysis should yield yield echo intensities, average Doppler velocities and spectral widths. Visualization methods are required to guide the fitting process with user intervention.

Clutter propagation characteristics

Improved understanding of the various detected signals will help devise optimized radar processors capable of compensating for propagation effects.

Measurements of fading and phase variation of microwave and optical signals have been carried out for a period over three decades now. Janes et al. (1970), for example, compared simultaneous line of sight signals at 9.6 and 34.5 GHz propagated over distances close to 65 km long in Hawaii. They found that the power spectra of fading were similar in shape at the two radio frequencies but with higher spectral density content at 34.5 GHz than at 9.6 GHz particularly in the range from 0.1 to 5 Hz. On the other hand, the power spectra of the phase variation– expressed in terms of parts per million change in radio path length– show identical power spectra from 0.01 to 5Hz and follow a power law f^{-n} with $n \approx 2.6$.

It is convenient to write the detected signal c in terms of its amplitude and phase,

$$c = |c|\, exp(i\,\varphi)\,. \tag{1}$$

These results can be extrapolated to describe fading and phase variation characteristics at frequencies of interest to us. For example, at 50 and 430 MHz $|c|$ will vary appreciably only for time scales longer than one minute. Phase changes, on the other hand, have the same functional form at all radio frequencies and they are linearly proportional to the probing frequency. Phase excursions will be 430/50 or 8.6 times bigger at 430 than at 50 MHz. Due to the exponential dependence in (1) –reminiscent of the FM communication mode– the bandwidth ratio at the two probing frequencies is bigger than 8.6.

Another source of clutter alteration that needs to be considered is the one produced by foliage disturbed by surface wind speeds.

At AO these effects can be studied simultaneously at the two frequencies mentioned previously. Moreover at 430 MHz it may be possible to detect two circular polarizations and use the one devoid of atmospheric echoes to neutralize the clutter. Of course, this procedure only works if both clutter polarizations are independent and proportional.

For completenes, albeit not related directly to clutter, let us mention that it is worth looking into the evaluation of the relative contribution of propagation vis-a-vis turbulence in the doppler widening of the signals in the GHz range.

Knowledge-based spectral analysis system

The knowledge-based system controls data processing. It is driven by data and it is responsive to a World Model. The model is defined in term of hypotheses and rules based in the the knowledge of specialists.

The expert system transforms the data as required using appropriate algorithms and verifies that the results comply with the rules of the world model. It is also capable of making inferences aimed toward conflict resolution.

Gradually, the expert system can grow in the learning curve and consequently demand less user assistance. Alternatively, it can grow to take on more complicated scattering environments for example, precipitation, lightning, foliage, ocean clutter etc..

It is is assumed here that the radar spectra can be described by Gaussian functions. Some of the rules that can guide the analysis process are mentioned next. Before, note that they are not as yet complete and that they will vary from station to station.

The following rules should help verify data integrity: a) adequate System Temperature values, b) S/N indicating system is in fact operating, c) real time quality flags to help document contingencies and to complement the observer's Log book.

Some further rules to assist in data processing are: a) reasonable upper bounds for the spectral widths of clutter, b) estipulation of plausible wind shears, c) acceptable time variability in the various parameters, and d) checks for frequency aliasing.

It is worth saying that sometimes fairly simple hints (e.g. Doppler shift is positive) can be valuable in the data reduction.

Signal Analysis System

To maximize the success of the signal processing algorithms the radar hardware has to work according to specifications and the experiments have to be well designed. At Arecibo for example, and as a matter of fact, it is not wise to use coded pulses to monitor the troposphere, or to carry on measurements while moving the antenna beam.

A brief description of the processing sequence is now in order.

The time series that results from coherently adding the returns needs to be examined first in order to subtract the clutter. Early subtraction of clutter has a double purpose: a) it reduces the distortion of the spectra of the atmospheric returns and of the noise, b) it presents the fitting algorithms with spectral data of comparable range of values. A sensitive issue here is the width of the notch filter to be used.

Proceed to obtain the spectra with the FFT algorithm, possibly weighting the data. And in the later case overlap data points to restore their information content. Optionally, run a median filter accross the spectra to account for outliers. Estimate and subtract the noise. Note that noise can be height dependent. Correct for coherent integrations (Farley, 1983). Display 2-D (frequency vs range) color or gray scale spectral profiles. To help focus on the true velocity profile this image can be examined with pattern recognition techniques to reject suspect features. At user request generate plots of spectral profiles. These plots should be flexible to allow diverse representations: Linear, log, normalized relative to a peak, normalized relative to the noise. Add a baseline value of a couple of dB to the 2-D periodograms to compensate for echo strength loss with range.

Interactively provide first guesses using the displays just described and proceed with the parameterization of the spectra. Fitting should be done locally around the frequency bins with spectral densities larger than the noise. Initially the fitting scheme should have at most 7 parameters: dc (1), Gaussians for clutter and atmospheric echoes (6). Overlay the results of the parameterization over the data plots. Assess quality of results using spatial– ranges above and below– and temporal– periods before and after– consensus criteria (Wilfong et al., 1992).

Accept or reject results of the analysis. In the former case save the parameters and the variables used in the analysis. Otherwise restart analysis procedure.

Gradually the expert system should control the analysis more exhaustively.

Conclusions

This work provides a framework to develop a robust data driven expert system to retrieve useful results from contaminated radar data. It summarizes some of the common wisdom dispersed in the literature (e.g. Wilfong et al., 1992) and intends to engage colleagues to contribute fresh approaches. It also constitutes the basis for a proposal for telescope time to the AO to study the effects of clutter and the means to ameliorate them.

In order to devise a knowledge-based system it is important to have adequate understanding of the various signals present at the receiving end. Similarly important is the formulation of rules whose compliance will guide the data reduction algorithms. Note that here there are three modules intervening in the analysis: data, inference system, and the algorithms.

It is worth stating that the verification of the rules of the expert system is a non trivial procedure and requires careful consideration. It is in general a difficult step to implement. It may use techniques borrowed from Pattern Recognition and rely on Interactive Visualization to permit effective user intervention.

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